



Fermi National Accelerator Laboratory

FERMILAB-Conf-94/270-E

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September 1994

Published Proceedings *Eighth Meeting of the Division of Particles and Fields of the American Physical Society (DPF'94)*, University of New Mexico, Albuquerque, New Mexico, August 2-6, 1994

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SEARCH FOR SUSY AT CDF

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ABSTRACT

We have searched supersymmetry (SUSY) using trilepton events in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV. In the Minimal Supersymmetric Standard Model (MSSM), trilepton events are expected from chargino-neutralino ($\tilde{\chi}_1^\pm \tilde{\chi}_2^0$) pair production, with subsequent decay into leptons. In all possible combinations of electron and muon channels in 19 pb^{-1} data, we observe no events which pass our trilepton selection criteria. Assuming the GUT hypothesis within the framework of the MSSM, our preliminary analysis excludes $M(\tilde{\chi}_1^\pm) < 46 \text{ GeV}/c^2$ for $-500 < \mu < -400 \text{ GeV}$, $2.0 < \tan\beta < 15.0$, and $M(\tilde{g}) = 1.2 \times M(\tilde{q})$.

1. Introduction

The first indication of supersymmetric grand unification arose from precision measurements of the Standard Model (SM) coupling constants $\alpha_1(Q)$, $\alpha_2(Q)$, and $\alpha_3(Q)$ at energy scale $Q = M(Z)$.¹ In the framework of SM with grand unification (GUT), there is no clear unification point. However, the coupling constants do indeed converge at the GUT scale when the Minimal Supersymmetric Standard Model (MSSM)² is embodied. This behavior suggests that SUSY must be involved in any reasonable approach to grand unification. Thus, a direct search for SUSY phenomena at high energy particle accelerators is clearly very important.

The most distinctive signatures of gluino ($\tilde{g}\tilde{g}$), squark ($\tilde{q}\tilde{q}$), gluino-squark ($\tilde{g}\tilde{q}$) and chargino-neutralino ($\tilde{\chi}_1^\pm \tilde{\chi}_2^0$) pair production are multi-jets associated with large missing transverse energy (\cancel{E}_T), same-sign dileptons and trilepton events. The multi-jets+ \cancel{E}_T approach is sensitive to $\tilde{g}\tilde{g}$, $\tilde{g}\tilde{q}$ and $\tilde{q}\tilde{q}$ production followed by direct cascade decays. Such a data analysis begins with a high \cancel{E}_T sample ($\cancel{E}_T > 40 \text{ GeV}$). The cross section for these events is large, but the details of \cancel{E}_T measurement must be well understood. Same-sign dilepton events probe $\tilde{g}\tilde{g}$ production, with corresponding cascade decays. Since this cross section is expected to be very small, much data is required for a sensitive measurement. Finally, trilepton events are one of the most promising channels for the discovery of SUSY at a hadron collider.³ Chargino-neutralino ($\tilde{\chi}_1^\pm \tilde{\chi}_2^0$) pairs are produced via s -channel virtual W 's or virtual squark exchange (t -channel), with subsequent leptonic decays ($\tilde{\chi}_1^\pm \rightarrow \ell\nu\tilde{\chi}_1^0$ and $\tilde{\chi}_2^0 \rightarrow \ell\bar{\ell}\tilde{\chi}_1^0$). The striking signature of these events is thus three isolated leptons, with minimal jet activity. Standard Model backgrounds in this mode are expected to be small.

Our data sample consists of 19 pb^{-1} total integrated luminosity of $\sqrt{s} = 1.8$ TeV $p\bar{p}$ collisions accumulated with the Collider Detector at Fermilab (CDF).⁴ These

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data were obtained during the 1992-93 run of the Fermilab Tevatron. In this paper, we present a preliminary search for SUSY trilepton events ($e^+e^-e^+$, $e^+e^-\mu^+$, $e^+\mu^-\mu^+$, and $\mu^+\mu^-\mu^+$) using this data sample.

2. Theoretical Predictions of the MSSM

Theoretical predictions of the MSSM were obtained using ISAJET Version 7.06⁵ with CTEQ2L structure function. We fixed the following parameters for our Monte Carlo (MC) simulations: $M(\text{top}) = 170 \text{ GeV}/c^2$, $M(H_A) = 500 \text{ GeV}/c^2$, $M(\tilde{q})/M(\tilde{g}) = 1.2$, $A_t = 0.0$, and $\alpha_s = 0.12$. Slepton and sneutrino masses were determined from $\tan\beta$, $M(\tilde{g})$, and $M(\tilde{q})$ using the renormalization group equations.⁶

3. Data Analysis

In order to be sensitive to $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ masses in the range 40-70 GeV/c^2 , our analysis begins with two data samples from the inclusive electron and muon triggers at $p_T^{\text{trig}}(\ell) = 9 \text{ GeV}/c$. The original inclusive e and μ samples contain 3.7M events ($19.11 \pm 0.76 \text{ pb}^{-1}$) and 2.7M events ($18.09 \pm 0.72 \text{ pb}^{-1}$), respectively.

We define two class of leptons: ‘gold’ and ‘ordinary’. Gold leptons are required to pass cuts which are tighter than the inclusive electron or muon trigger criteria. The minimum gold lepton p_T is 11 GeV/c (avoiding the turn-on region of 9 GeV/c trigger threshold) and gold electrons (muons) are accepted in the pseudo-rapidity range $|\eta| < 1.1$ ($|\eta| < 0.6$). The ordinary leptons have lower E_T or p_T thresholds and generally pass looser quality cuts. The minimum p_T value for ordinary electrons (muons) is 5 GeV (4 GeV/c); ordinary electrons (muons) are accepted in the pseudo-rapidity range $|\eta| < 2.4$ ($|\eta| < 1.2$). Details of the lepton selection criteria can be found elsewhere.⁷

The event must contain three isolated leptons in which at least one should be the gold lepton. The isolation variable ISO is defined as the total transverse energy within a cone of $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.4$ around the lepton (excluding the lepton E_T). After all requirements ($ISO < 2 \text{ GeV}$, $|Z_{\text{vertex}}| < 60 \text{ cm}$, $\Delta R_{\ell\ell} > 0.4$, $\Delta\phi(\ell_1\ell_2) < 170^\circ$, existence of e^+e^- or $\mu^+\mu^-$, removal of Z^0 , J/ψ and Υ),⁸ we are left with zero event candidates.

4. Detection Efficiency

The total detection efficiency for $\tilde{\chi}_1^\pm\tilde{\chi}_2^0 \rightarrow 3\ell X$ is defined as

$$\epsilon^{\text{tot}} = \sum_{xxx} (\epsilon_{xxx}^{\text{trig}} \cdot \epsilon_{xxx}^{\text{MC}} \cdot \epsilon^{ISO}) \quad (1)$$

where: ϵ^{trig} is the trigger efficiency ($p_T > 11 \text{ GeV}/c$); ϵ^{MC} is the acceptance with all analysis cuts excluding the isolation requirement ($ISO < 2 \text{ GeV}$); ϵ^{ISO} is the efficiency of the $ISO < 2 \text{ GeV}$ requirement alone; $xxx = e^+e^-e^+$, $e^+e^-\mu^+$, $e^+\mu^-\mu^+$, or $\mu^+\mu^-\mu^+$ mode.

The trigger efficiency for each mode is estimated to be an average of the single lepton trigger efficiencies, weighted according to the lepton content in the mode. For

example, $\epsilon_{ee\mu}^{trig} = \frac{2}{3}\epsilon_e^{trig} + \frac{1}{3}\epsilon_\mu^{trig} \cdot C$, where $\epsilon_\mu^{trig} = (84.33 \pm 2.30)\%$, $\epsilon_e^{trig} = (87.73 \pm 1.53)\%$, and $C = 0.95$. The factor C is applied to the muon trigger efficiency only and corrects for a difference in total integrated luminosity available in the inclusive muon and inclusive electron data samples (due primarily to different numbers of bad runs, in which the muon or electron detectors experienced problems). Thus, this correction factor gives us an “effective” muon trigger efficiency.

The trilepton event acceptance (ϵ^{MC}) was determined as a function of $M(\tilde{\chi}_1^\pm)$ from ISAJET + QFL (a CDF detector simulation). The acceptance is found to be quite linear over the mass range of interest ($40 < M(\tilde{\chi}_1^\pm) < 70$ GeV/c²). Therefore, we have fit straight lines through the data points and will use the equations of these lines as closed form expressions of ϵ^{MC} .⁸ For example, $\Sigma\epsilon_{eee}^{MC} = 18\%$ at $M(\tilde{\chi}_1^\pm) = 50$ GeV/c².

The isolation efficiency ϵ^{ISO} was determined from data to be 88%⁷ and is equivalent for each mode.

5. Backgrounds

The principal backgrounds to the SUSY trilepton analysis are from Drell-Yan, $Z + X$, diboson (WZ, ZZ), and $b\bar{b}$ events. Each of these processes (forcing leptonic decays only, and forcing τ 's to decay to e or μ) generated by ISAJET were run through QFL, the offline reconstruction software and the trilepton finding code. Drell-Yan and $Z + X$ both can produce two leptons directly and may only be mistaken for a SUSY trilepton if there is a third “fake” lepton in the event. We use the term “fake” to mean incorrectly identified leptons, leptons from photon conversions, decays in flight, etc. The fake probability of $0.25 \pm 0.03\%$ ⁸ is used for this estimate.

The total background yield expected in 19 pb⁻¹ data is 0.75 events.⁸ The dominant background source is Drell-Yan (0.61 events). This is completely consistent with our observation of zero events.

6. Excluded Regions of the MSSM

Our observation of zero trilepton events folded in with our statistical and systematic uncertainties, determines an upper limit on $M(\tilde{\chi}_1^\pm)$. The total systematic uncertainty of 19%⁸ is convoluted (as a Gaussian smearing) with a Poisson distribution, we obtain a 95% confidence level upper limit of 3.2 events. The upper limit to $\sigma \cdot BR$ is:

$$\sigma \cdot BR(\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow 3\ell X) < \frac{3.2}{\int \mathcal{L} dt \cdot \epsilon^{tot}} \quad (2)$$

where $\int \mathcal{L} dt$ is the integrated luminosity for our data sample (19.11 pb⁻¹), ϵ^{tot} is the total detection efficiency (Eq. 1), and $BR(\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow 3\ell X) \equiv BR(\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow eeeX) = BR(\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow e\mu\mu X) = BR(\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow eee\mu X) = BR(\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow \mu\mu\mu X)$.

Figure 1 shows the 95% confidence level upper limit on $\sigma \cdot BR(\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow 3\ell X)$, plotted as a smooth curve vs. $M(\tilde{\chi}_1^\pm)$. The points in the figure are the ISAJET predictions for $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ production from several different $\tan\beta$ values at $\mu = -400$ GeV. It is apparent that $M(\tilde{\chi}_1^\pm) < 46$ GeV/c² are excluded by our data. The approximate \tilde{g} mass

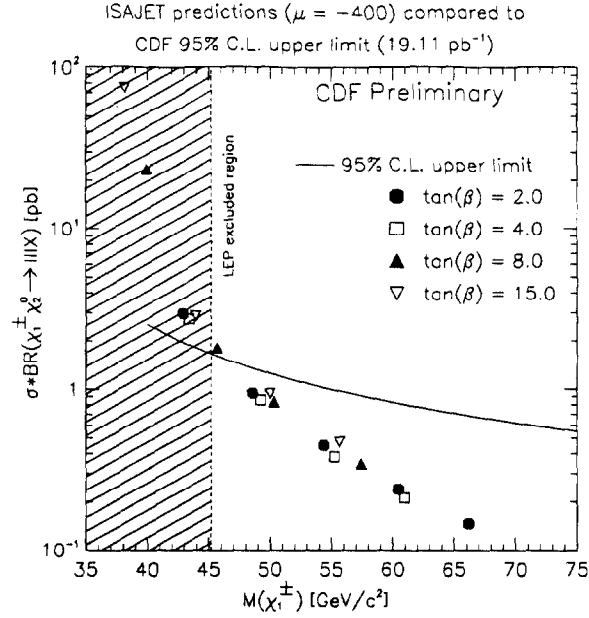


Fig. 1. 95% confidence level upper limit on $\sigma\text{BR}(\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow 3\ell X)$ vs. $M(\tilde{\chi}_1^\pm)$. The data points are the predictions of ISAJET. The shaded region corresponds to the LEP limit.⁹

values which correspond to $M(\tilde{\chi}_1^\pm) = 46 \text{ GeV}/c^2$ are 131, 149, 161, and 167 GeV/c^2 at $\tan\beta = 2, 4, 8$, and 15, respectively.

The ISAJET MC points for $\mu = -500 \text{ GeV}$ (not shown) describe an identical curve and yield the same 46 GeV/c^2 upper limit. This limit is comparable to the LEP result.⁹

In summary, we have searched for evidence of the production and decay of SUSY chargino-neutralino pairs into trilepton events in 19 pb^{-1} of $\sqrt{s} = 1.8 \text{ TeV}$ $p\bar{p}$ collision data at CDF. Using all possible electron and muon decay channels, no events are observed. We exclude $M(\tilde{\chi}_1^\pm) < 46 \text{ GeV}/c^2$ for the MSSM parameter values previously stated.

Acknowledgements

We would like to thank Drs. R. Arnowitt and J. Lopez for useful discussions and Mr. B. Tannenbaum for his parameter scanning program. We also thank the Fermilab staff and the technical staffs of the participating institutions for their vital contributions. This work was supported by the U.S. Department of Energy and National Science Foundation; the Italian Istituto Nazionale di Fisica Nucleare; the Ministry of Education, Science and Culture of Japan; the Natural Sciences and Engineering Research

Council of Canada; the National Science Council of the Republic of China; the A. P. Sloan Foundation; and the Alexander von Humboldt-Stiftung.

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